Nano-Second Response, Polarization Insensitive and Low-Power Consumption PLZT 4x4 Matrix Optical Switch

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Abstract: A strictly non-blocking PLZT 4x4 optical switch with less than 10 ns response is developed. The switch consisted of 24-1x2 switch elements which have polarization insensitivity and low-power consumption is integrated on a single chip.
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1. Introduction

Recently, there are increasing interests in nano-second speed optical switches. Such a trend is driven by applications such as optical packet switching systems, burst switching systems, high-speed protections, and active access systems. However, there have been very limited demonstrations on nano-second speed NxN optical switches although nano-second speed 1xN optical switches have been developed [1,2] and (Pb,La)(Zr,Ti)O_3 (PLZT) waveguide based nano-second speed 1xN optical switches have been used for system prototypes [3-6]. That is because there have been challenges due to the complicated structure of a NxN switch as compared with a 1xN switch. Actually, a strictly non-blocking NxN switch needs 2Nx(N-1) 1x2 switch elements and crossing waveguides although a 1xN switch needs only N-1 switch elements.

PLZT is an efficient and polarization insensitive electro-optic material. The PLZT waveguide we developed has a buried core structure [7] which minimizes absorption loss caused by a top electrode and a substrate. To construct NxN optical switch with PLZT waveguides, however, optimizations of 1x2 switch elements, crossings, and S-bends are further needed to minimize insertion loss and non-uniformity of switch elements. Requirements for the 1x2 switch elements include nano-second response, small size to make a 4x4 switch compact, polarization insensitivity, and low insertion loss. The crossing angle and cross point structure should be optimized to make crosstalk small and crossing loss small. The S-bends should have small bending radius to make 4x4 switch compact to the extent radiation loss is small. We report a nano-second speed strictly non-blocking 4x4 optical switch with high extinction ratio and polarization insensitivity achieved through the optimizations of design and fabrication process.

2. 4x4 Switch Fabrication Process

The buried core PLZT waveguide is grown by unique solid-phase epitaxy (SPE) which can produce a high-quality low-loss thin film waveguide. The SPE process for PLZT thin-film is composed of a precursor solution deposition step and a rapid thermal annealing step to crystallize PLZT epitaxially. A PLZT bottom clad layer and a PLZT core layer are grown by the SPE on a Nb-doped $NbTiO_3$ (NST) semiconductor wafer. A 3 um-wide channel-waveguide is formed by an ICP etching process and planarized with top clad by SPE growth. The core layer has higher index than the clad layers to confine the light in the core layer. The clad layers prevent optical absorption by the NST and top electrodes. An indium-tin oxide top electrode layer with a Au contact layer is fabricated on the surface of the PLZT channel waveguides using a sputtering and a lift-off process. A cross-sectional structure of the PLZT buried waveguide is shown in Fig. 1. The top electrodes are connected to bond pads by Au interconnects. Edge facets are optically polished after dicing.

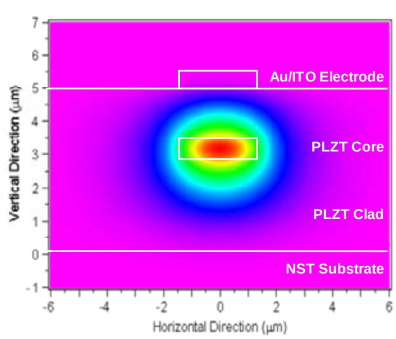

Fig. 1. A simulated PLZT buried waveguide structure.

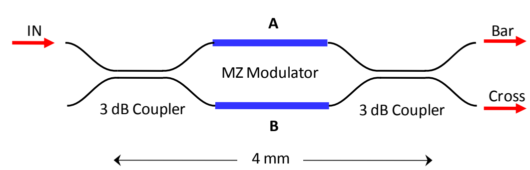

Fig. 2. 1x2 MZ optical switch structure.

3. 4x4 Switch Performance

A 4x4 switch is consisted of twenty four 1x2 switch elements ad building blocks. The building block 1x2 switch element is a modified balance bridge type switch composed of a MZ modulator with top electrodes and input and output 3dB couplers as shown in Fig. 2. An input optical signal is delivered to the cross port and bar port under no voltage application (3 dB splitting state). By applying a voltage to one of top electrodes (A is on or B is on), the signal is promptly switched to the cross port or the bar port due to the resulting electro-optic index change. Fig. 3 shows a typical switching curve for the TE polarized 1550 nm wavelength in a fabricated 1x2 switch as a function of voltage application to the electrode B. Insertion loss, PDL, and crosstalk/extinction ratio are 4.5 dB, 0.1 dB, and 25 dB at 7.5V, respectively. A typical crosstalk in a fabricated matrix 2x2 switch consisted of four 1x2 switch elements is 35 dB with a support of a two stage switch architecture.

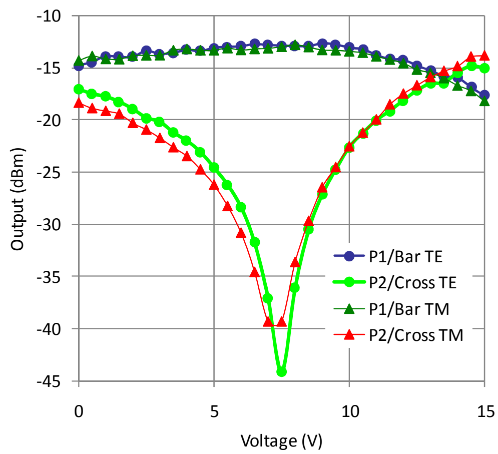

Fig. 3. Switching curve for 1x2 switch.

The 4x4 switch has a strictly non-blocking tree structure as shown in Fig. 4. An optical signal from any input port is delivered to any output port without disturbing other connections. A 4x4 switch chip has a length of about 22 mm after optimization of 1x2 switch elements, crossings, and S-bends by BPM simulations. Fig. 5 shows a fabricated 4x4 PLZT switch chip. A packaged 4x4 switch is mounted in a 19 inch rack with a high-speed driving circuit as a subsystem. The driving circuit gives 10V at around 5 ns speed to the twenty four 1x2 switch elements in the 4x4 switch. The optical switching time is around 8 ns as shown in Fig. 7. A network based on the nano-second PLZT switch can switch frequently to allocate the bandwidth efficiently. That is because the high switching speeds allow guard time to be minimized. On the other hand, a network based on a conventional milli-second speed switch is not efficient because its switching overhead is very large as compared with data size. Therefore, this drastic reduction in guard time makes data transfer very efficient and realistic in networks including optical packet switching, optical burst switching, and time division slot switching.

The tree structure 4x4 has two stage switch nature as well as the 2x2 switch. The first stage switches and the second stage switches work as delivery switches and the third stage switches and the fourth stage switches work as gate switches so that cross talk can be minimized. Tab. 1 shows insertion loss, PDL, crosstalk, and extinction ratio for the connection from input port 1 to four output ports in a fabricated 4x4 switch. The insertion loss is around 12 dB~13 dB and the loss nonuniformity is 1.4 dB~1.9 dB range. Relatively large loss is due to minor defects in the waveguide and residual electrode and substrate absorption loss. Those losses could be minimized to obtain less than 10 dB insertion loss by process improvement and design optimization. The PDL is less than 1 dB except for P1 to P4 connection. The P1 to P4 PDL is 1.8 dB due to remaining polarization dependence of 1x2 switch elements associated with non-uniformity of the 1x2 switching elements. It could be minimized by process optimization. The crosstalk and extinction ratio are 33 dB~39 dB range which could be acceptable for optical network applications.

Estimated power consumption of the 4x4 switch chip is as low as 490 mW at 10MHz since PLZT switch is a voltage drive type device with a negligible leakage current. Power consumption of a 4x4 switching subsystem including a driving electronics is 5W at 1MHz or 13W at 10MHz. Such a low power consumption characteristic would be very suitable not only for future optical packet switching systems but also for existing optical network nodes.

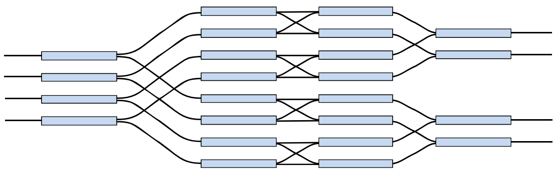

Fig. 4. Tree structure 4x4 switch.

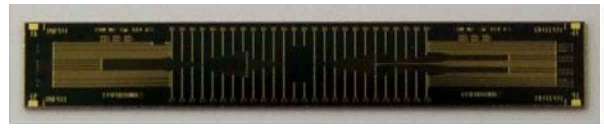

Fig. 5. PLZT 4x4 switch chip.

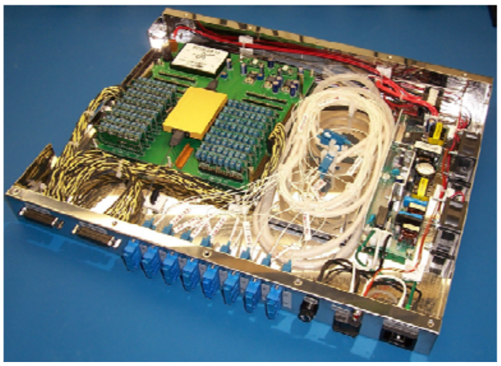

Fig. 6. 19 inch rack mounted PLZT 4x4 switch.

Fig. 7. Optical raise signal form in 4x4 switch.

Tab. 1. IL, PDL, CT, and ER in 4x4 switch.

In		P1				Uniformity
Out		P1	P2	P3	P4	
IL (dB)	TE	13.9	13.1	12.0	13.0	1.9
	TM	13.2	12.3	11.7	14.8	1.4
PDL (dB)		0.7	0.8	0.3	1.8	
CT/ER (dB)	P1	0.0	36.7	38.5	37.8	
	P4	35.5	32.9	36.7	0	

4. Conclusions

A nano-second speed 4x4 optical switch using PLZT waveguides was reported. The 4x4 switch showed the switching speed less than 10 ns successfully. The insertion loss and PDL were around 12 dB~13 dB and 0.3 dB~1.8 dB, respectively. The crosstalk and the extinction ratio were 33 dB~39 dB. The developed PLZT 4x4 optical switches will be of key enabler for optical packet/burst based networks and useful for energy efficient optical networks.

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